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Research Paper

MECHANICAL PROPERTIES OF FIBER REINFORCED COMPOSITES USING FINITE ELEMENT METHOD

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The micromechanical analysis plays a very important role in the composite materials. These studies explore average mechanical properties of composites materials with good accuracy. The properties of any composite material depends on the constituents, loading, geometry, inter phase region and environmental conditions. The proposed work focus on the evaluation of properties of the fiber reinforced composite material with different volume fraction under different loading conditions. The 3D finite element model with governing boundary conditions has been developed from the unit cell of square pattern of the composite to evaluate engineering constants like, longitudinal modulus (E_1), transverse modulus (E_2), major poissons ratio ($\neg_{12}$) and minor Poisson's ratio ($\neg_{21}$) of the fiber reinforced composites for different fiber volume fractions considering uniform and random distribution of reinforcement. The predictions of the present work are validated with analytical expressions. The present work will be useful to predict the engineering constants of uniform and random distribution of fiber in FRP composites subjected to longitudinal and transverse loading.

Keywords: Mechanical properties, Fiber, Composite materials, Finite element method, FRP composties

INTRODUCTION

Engineering materials are classified into three broad categories; metals, ceramics and polymers. Composites are combinations of two or more materials from one or more of these categories. One of the phase is usually discontinuous, stiffer, and stronger and is called reinforcement, whereas the less stiff and weaker phase is continuous is called the matrix. The combination results in superior properties not exhibited by the individual materials. Mostly the properties of interest in composites are the mechanical properties. A composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers,

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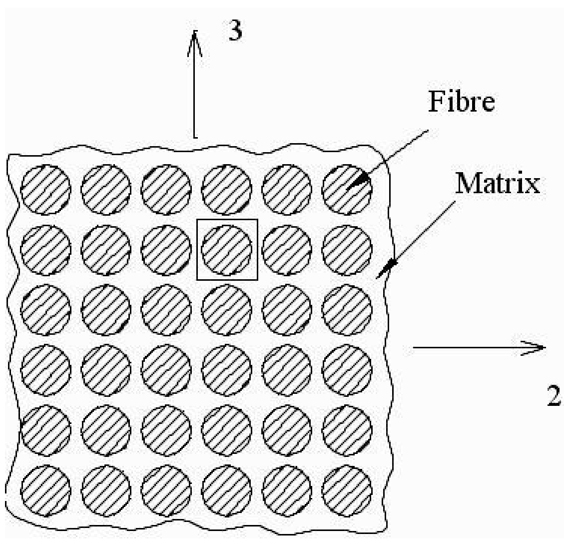
metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. The key parameters of interest in fiber reinforced composites are specific strength and specific modulus. Specific strength is defined as the ratio of tensile strength to the specific gravity. Specific modulus is defined as the ratio of modulus of elasticity to the specific gravity. The fiber reinforced composites can be a tailor made, as their properties can be controlled by the appropriate selection of the substrata parameters such as fiber orientation, volume fraction, fiber spacing, and layer sequence. The required directional properties can be achieved in the case of fiber reinforced composites by properly selecting fiber orientation, fiber volume fraction, fiber spacing, and fiber distribution in the matrix and layer sequence. As a result of this, the designer can have a tailor-made material with the desired properties. Such a material design reduces the weight and improves the performance of the composite. Shokrieh and Ghanei Mohammadi (2010), Lei *et al.* (2012) and Syam Prasad *et al.* (2013) have developed predictive models for the uni-directional short fiber-reinforced composites and investigate the distribution effect of the short fibers. Sreedhar Kari *et al.* (2007), have developed predictive models for micromechanical analysis of fiber reinforced composites with various types of constituents. Harald Berger *et al.* (2007), Srivastava *et al.* (2011), Anurag Bajpai *et al.* (2012) and Marek Romanowicz (2013) have developed the material properties of spherical particle reinforced composites for different volume fractions upto 60%. Dragan Kreculj (2008), stresses in the models from uni-directional carbon/epoxy composite material are studied using Finite Element Method (FEM), can be used in order to predict stress distribution on the examined model.

In this paper the material properties are predicted for the uniform distribution of fiber reinforced composites and random distribution of fiber reinforced composites. The engineering constants E_1, E_2, $\neg_{12}$, $\neg_{21}$, $\neg_{13}$, $\neg_{23}$ are determined for both the cases and are compared with the rule of mixtures and Halphin-Tsai criteria.

METHODOLOGY

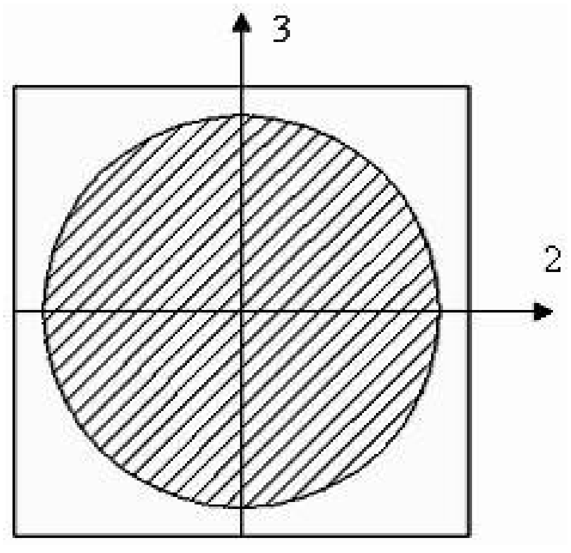
The present research work deals with the evaluation of engineering properties by the elastic theory based on finite element analysis of representative volume elements of fiber-reinforced composites. The fibers are arranged in the square array which is known as the uni-directional composite. And this uni-directional fiber composite is shown in Figure 1. It is assumed that the fiber and matrix materials are linearly elastic. A unit cell is

Figure 1: Concept of Unit Cells



adopted for the analysis. The measure of the volume of fiber relative to that total volume of the composite is taken from the cross-sectional areas of the fiber relative to the total cross-sectional area of the unit cell. This fraction is considered as an important parameter in composite materials and is called fiber volume fraction (V_f).

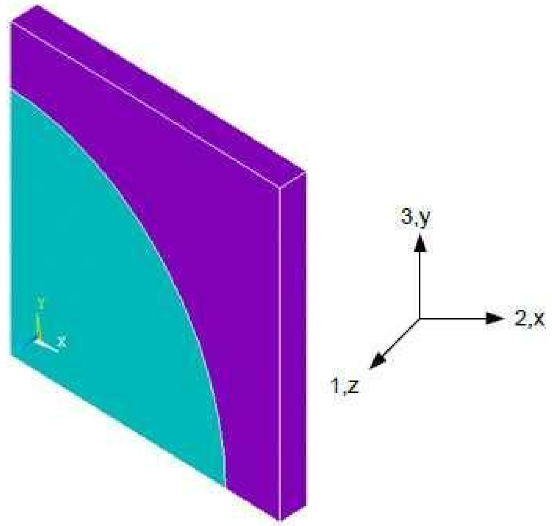
Figure 2: Isolated Unit Cells of Square Packed Array



Finite Element Model

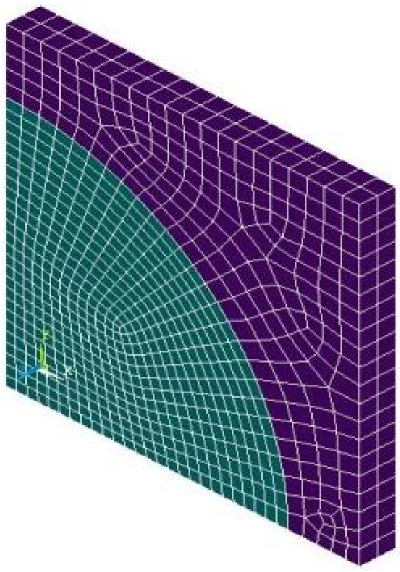
In the study of the Micromechanics of fiber reinforced materials, it is convenient to use an orthogonal coordinate system that has one axis aligned with the fiber direction. The 1-2-3 Coordinate system shown in Figure 3 is used to study the behavior of unit cell. The 1 axis is aligned with the fiber direction, the 2 axis is in the plane of the unit cell and perpendicular to the fibers and the 3 axis is perpendicular to the plane of the unit cell and is also perpendicular to the fibers. The isolated unit cell behaves as a part of large array of unit cells by satisfying the conditions that the boundaries of the isolated unit cell remain plane.

Figure 3: One Fourth Portion of Unit Cell



Due to symmetry in the geometry, material and loading of unit cell with respect to 1-2-3 coordinate system it is assumed that one fourth of the unit cell is sufficient to carry out the present analysis. The 3D Finite Element mesh on one fourth portion of the unit cell is shown in Figure 4.

Figure 4: Finite Element Mesh Model



Geometry

The dimensions of the finite element model are taken as:

X = 100 units,

Y = 100 units,

Z = 10 units.

The radius of fiber is calculated is varied to the corresponding fiber volume.

Element Type

The element SOLID95 of ANSYS V13.0 used for present analysis is based on a general 3D state of stress and is suited for modeling 3D solid structure under 3D loading. SOLID95 is a higher-order version of the 3D 8-node solid element SOLID45. It can tolerate irregular shapes without as much loss of accuracy. SOLID95 elements have compatible displacement shapes and are well suited to model curved boundaries. SOLID95 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. The element has 20 nodes having one degree of freedom, i.e., temperature and with three degrees of freedom at each node: translation in the node X, Y, Z directions respectively.

Boundary Conditions

Due to symmetry of the problem, the following symmetric boundary conditions are used:

- At X = 0, $U_X = 0$
- At Y = 0, $U_Y = 0$
- At Z = 0, $U_Z = 0$

In addition, the following multi point constraints are used.

- The U_X of all the nodes on the Area at X = 100 is same
- The U_Y of all the nodes on the Area at Y = 100 is same
- The U_Z of all the nodes on the Area at Z = 10 is same

Analytical Solution

The mechanical properties of the lamina are calculated using the following expressions of Theory of elasticity approach and Halphin-Tsai's formulae. Young's Modulus in the fiber direction and transverse direction.

E_1 = ±$_1$/£$_1$

E_2 = ±$_2$/£$_2$

Major poison's ratio ¬$_{12}$ = –£$_2$/£$_1$

where

±$_1$ = stress in X-direction

±$_2$ = stress in Y-direction

£$_1$ = strain in X-direction

£$_2$ = strain in Y-direction

Rule of Mixtures

Longitudinal young's modulus: $E_1 = E_f V_f + E_m V_m$

Transverse young's modulus: $E_2 = E_f V_f + E_m V_m$

Major poison's ratio: ¬$_{12}$ = ¬$_f V_f$ + ¬$_m V_m$

RESULTS

In the present work finite element analysis has been carried out to predict the engineering constants of uniform and random distribution fibers in fibre reinforced particulate composite. The results obtained are validated with the results obtained by Rule of Mixtures and Halpin-Tsai.

Uniform Distribution of Fiber (Boron) in an FRP Composite

The variation of different engineering constants of a uniform distribution of boron fiber/Epoxy composite with respect to the different volume fractions is shown.

The variation of longitudinal Young's modulus (E_1) with respect to volume fraction of fiber. The response of E_1 of composite material is increasing in linear manner with the variation of fiber content (V_f). This is due to the improvement in stiffness of resulting composite material (Figure 5). The variation

Figure 5: Variation of E_1 with Fiber Volume Fraction

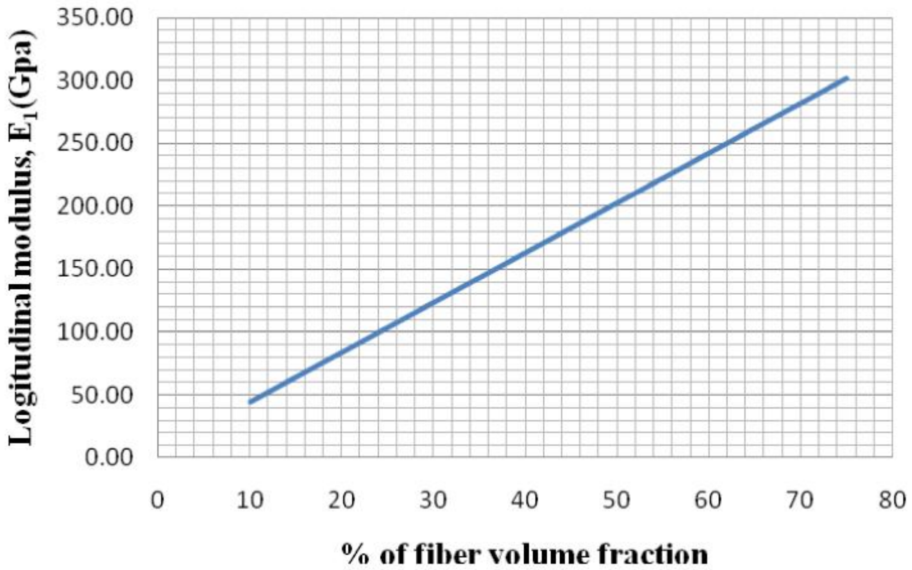
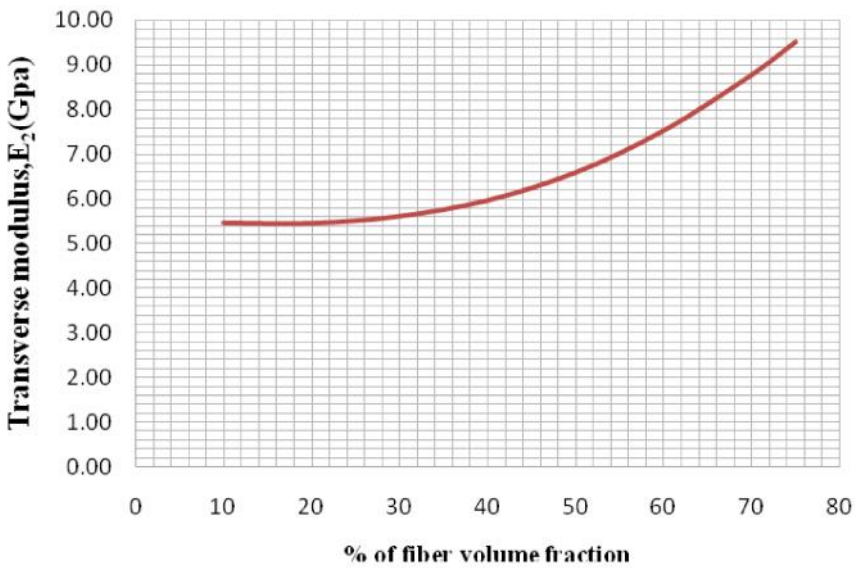


Figure 6: Variation of E_2 with Fiber Volume Fraction



of Transverse modulus (E_2) following the same trend as that of longitudinal modulus but in non linear way (Figure 6). The longitudinal poissons ratios (ν_{12} and ν_{13}) are yielded same response and their magnitude is decreases as the stiffness of composite material increases (V_f) (Figure 7). The transverse poissons ratio ν_{21} is decreased sharply upto 40% V_f later no significant change is observed (Figure 8). The transverse poissons ratio ν_{23} showed different response compared with other poissons ratios. It is low at lower volume fractions and maintained steady response with the increment of volume fraction (Figure 9).

Figure 7: Variation of ¬$_{12}$ with Fiber Volume Fraction

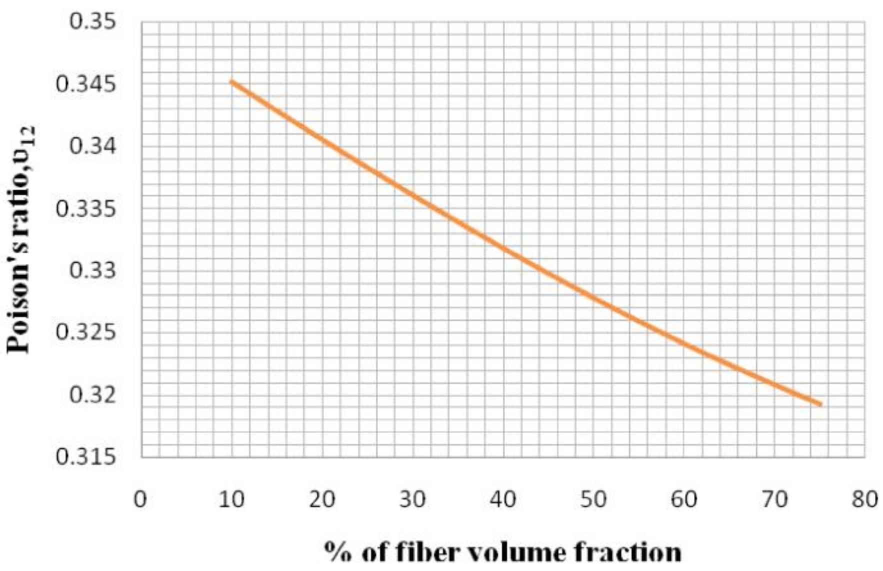


Figure 8: Variation of ¬$_{13}$ with Fiber Volume Fraction

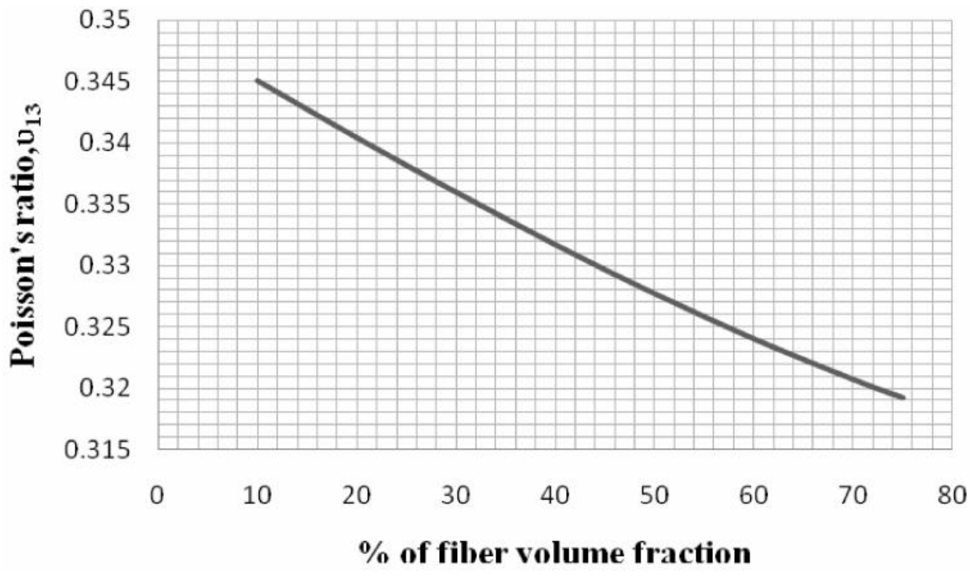


Figure 9: Variation of ν_{21} with Fiber Volume Fraction

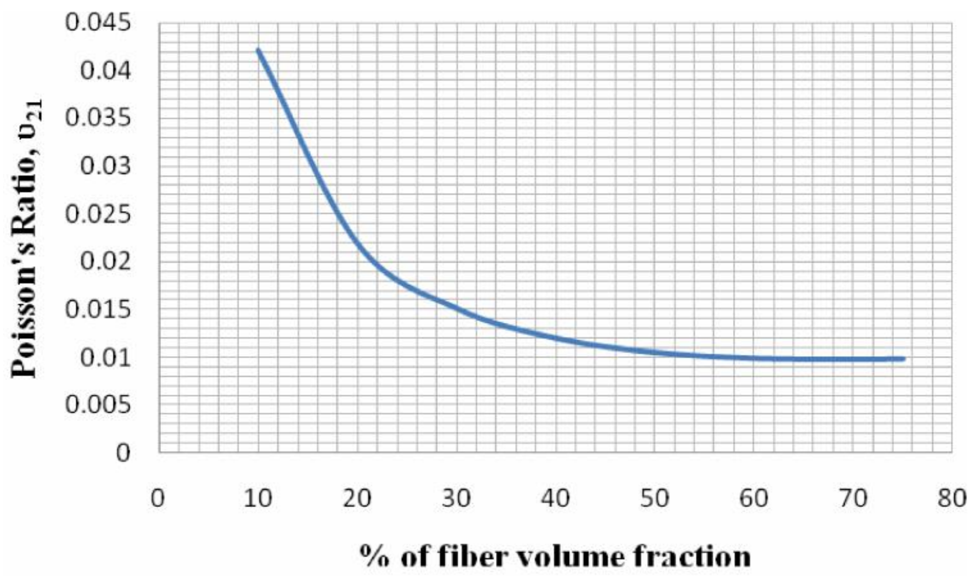
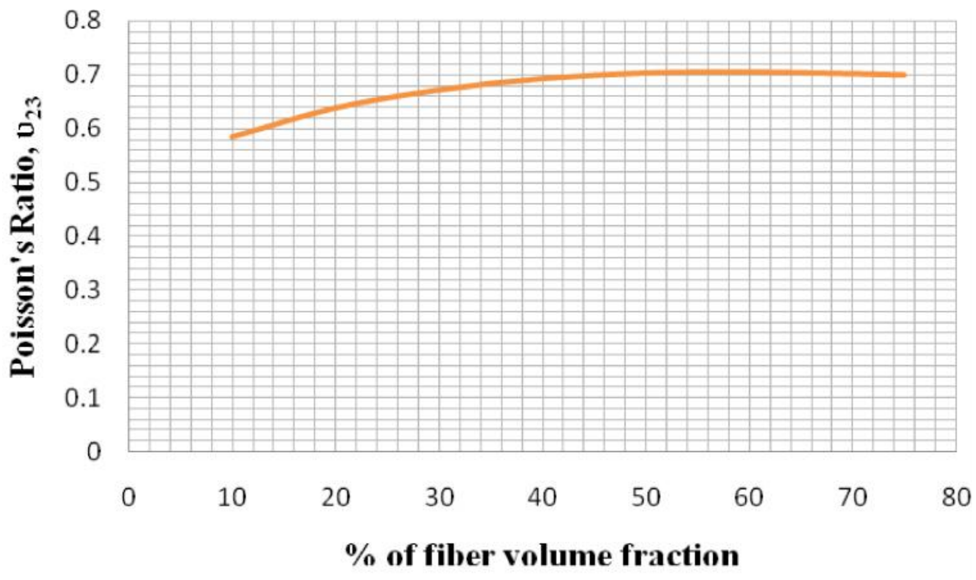


Figure 10: Variation of ν_{23} with Fiber Volume Fraction



Random Distribution of Boron Fiber in an FRP Composite

The variation in different engineering constants of a random distributed Boron fiber in epoxy matrix with respect to the different fiber volume fractions is shown below. The properties for randomly distribution of reinforcement is mentioned in terms of bounds. The minimum and maximum properties for randomly distributed reinforcement are presented. The effect of randomly distributed boron fibers is not observed in longitudinal Young's modulus (E_1), i.e., the maximum and minimum properties are same for concerned random distribution (Figure 11). The transverse Young's modulus is considerable changes are gained due to random distribution and the changes are minimum at lower and higher volume fraction of fiber reinforcement and maximum deviation is observed at intermediate volume fractions (Figure 12). The same trend is observed for longitudinal poissons ratio ($¬_{12}$, $¬_{13}$) and Transverse poissons ratio ($¬_{23}$) (Figures 13, 14 and 16). Difference scenario is obtained for Transverse modulus ($¬_{21}$) at fiber dominated volume fractions the maximum and minimum are quite alike (Figure 15).

Figure 11: Variation of E_1 with Fiber Volume Fraction

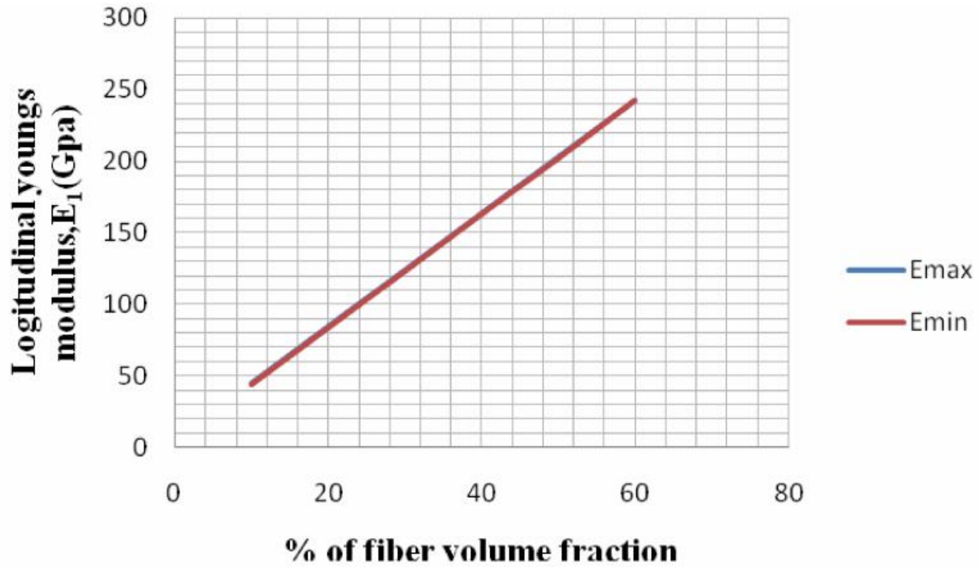


Figure 12: Variation of E_2 with Fiber Volume Fraction

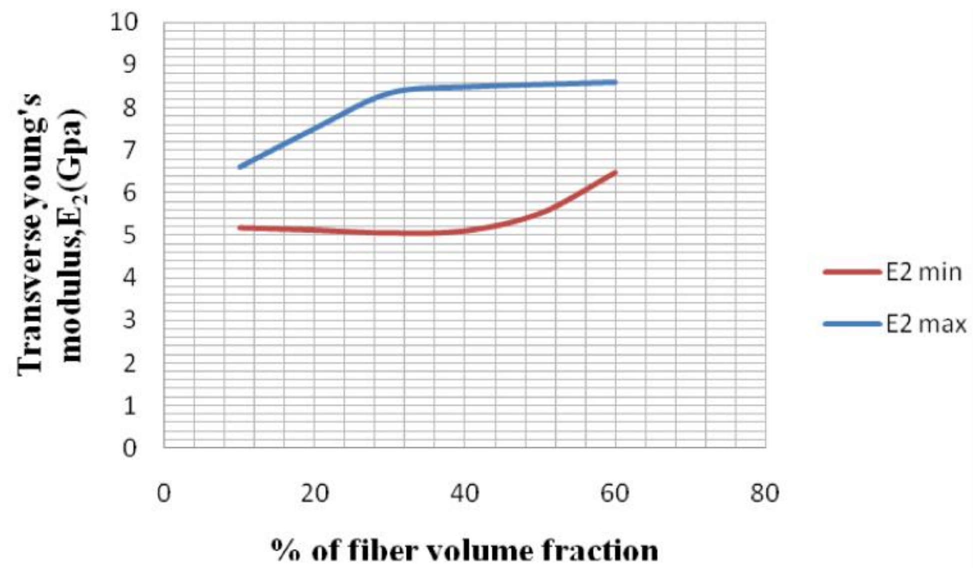


Figure 13: Variation of $¬_{12}$ With Fiber Volume Fraction

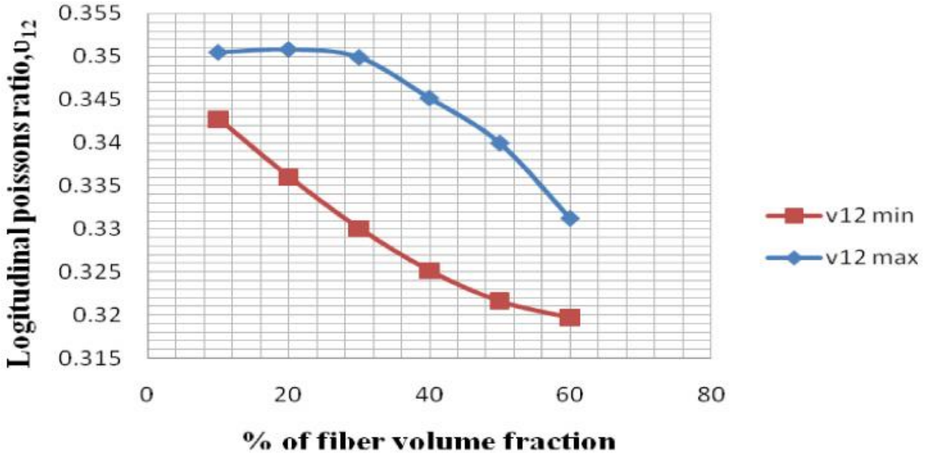


Figure 14: Variation of $¬_{13}$ with Fiber Volume Fraction

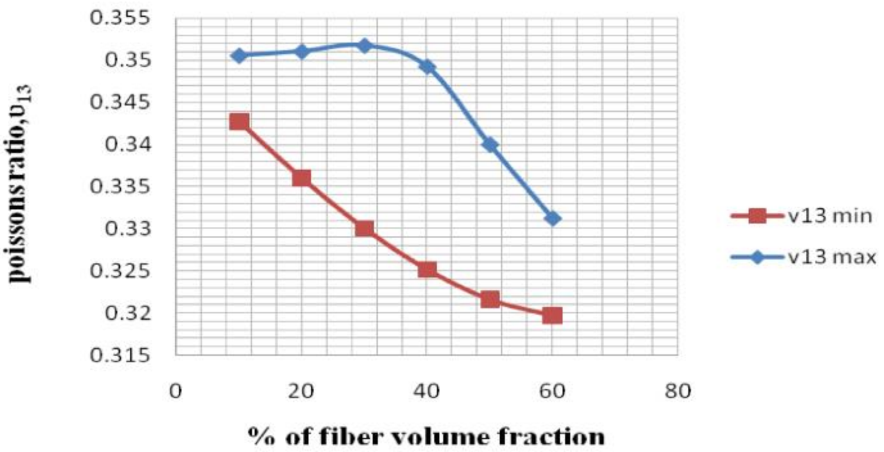


Figure 15: Variation of $¬_{21}$ with Fiber Volume Fraction

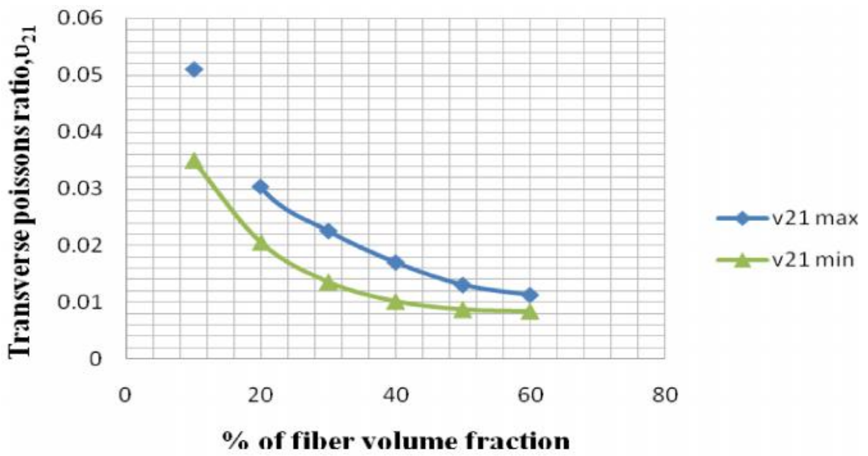
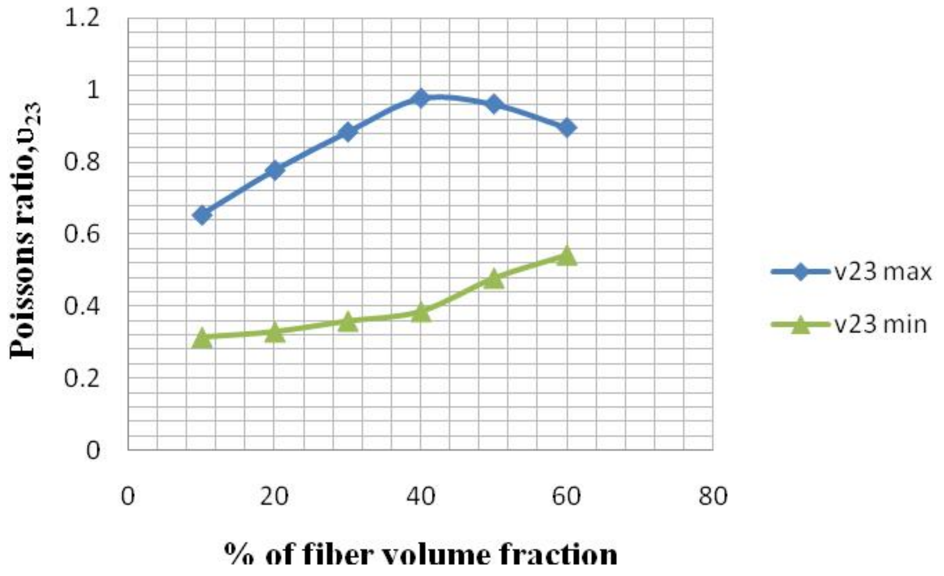


Figure 16: Variation of ¬$_{23}$ with Fiber Volume Fraction



CONCLUSION

The finite element method is very useful tool to extract the average properties of composite materials. The influence of reinforcement distribution in mechanical properties of composite material is presented by adopting finite element method and micromechanics approach. Compared with uniform distribution, the random distribution of boron fiber is significant in terms of mechanical properties particularly in transverse properties.

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